TILT ROTOR UNMANNED AIR VEHICLE SYSTEM (TRUS) DEMONSTRATOR FLIGHT TEST PROGRAM

by
Michael J. Meyers
Rotary Wing Aircraft Test Directorate
Naval Air Warfare Center, Patuxent River, MD 20670-5304

The Tilt Rotor UAV System flight demonstration program commenced in July 1993 and concluded with conversion to airplane mode and a level flight speed of 160 kts in February 1994. The purpose of the flight tests was to evaluate the utility of Tilt Rotor UAV technology in order to develop requirements for a Government maritime system. The TRUS program was divided into three test phases; Ground, Helicopter Mode, and Coversion to Airplane Mode. Helicopter Mode testing occurred at the contractor's facilities in Fort Worth, TX over two periods and consisted of fourteen flights totaling 3.0 flight-hours. During phase II, the aircraft conducted IGE (In Ground Effect) and OGE (Out of Ground Effect) hovers, longitudinal and lateral translations at up to 20 kts, as well as pitch, roll, and yaw control response testing. Handling qualities during the takeoff and landing flight regimes were also assessed. Phase III, conversion to airplane mode testing occurred at the Yuma Proving Grounds, AZ during January and February of 1994 and consisted of eleven flights totaling 8.4 flight hours. While at YPG, the aircraft nacelles were incrementally converted forward over a series of ten flights from helicopter mode (93 to 85 degrees) to full airplane mode (zero degrees). After successful conversion testing was completed, the forward flight envelope was increased from 135 to 160 kts. The information and data obtained during the TRUS flight demonstration will be used to develop the requirements for a production maritime UAV system.

DESCRIPTION OF TEST AIRCRAFT

The TRUS air vehicle is a high performance tilt rotor UAV powered by a single turboshaft Allison 250-C20B engine. The empty gross weight of the aircraft was 1471.6 lbs. The maximum takeoff gross weight tested was 1779.5 lb. The modular airframe, which was built by Burt Rutan's company; Scaled Composites was constructed primarily of a combination of graphite and fiberglass materials bonded with room-temperature cured resin. Two three bladed gimbaled rotors were mounted on wing tip tilting pylons. The pylons had a range of motion between zero degrees (airplane mode), and 93 degrees which was maximum aft nacelle tilt in helicopter mode. The rotors were driven by a transmission consisting of a mid-wing mounted "T" gearbox, interconnected to drive shafts in each wing, and a pair of 90 degree gearboxes at the wing tips. As part of a risk reduction and cost savings measure, most of the hardware used in the design came from components available on the Bell helicopter production lines. JP-5 fuel was stored in a main tank located in the fuselage below the main wing box and in the wings using a "wet wing" arrangement. The total fuel capacity of the TRUS was 60 gal or approximately 410 lb of JP-5. Fuel receptacles were located on the top of each wing and were compatible with standard aviation fueling equipment. The TRUS air vehicle's landing gear consisted of fuselage mounted retractable centerline main gear, and small stabilizing gear mounted at the ends of the pylons.

2880

The TRUS vehicle air data terminal (ADT) transmitted and received information to and from the ground data terminal (GDT). The ADT downlink was a single C-band transmitter. Guidance commands received by the ADT were passed to the digital central processor assembly (DCPA) where the signal was decoded. The DCPA in turn passed the commands to the flight control computer (FCC). Onboard sensors such as the ring laser gyro integrated flight management unit (IFMU), the air data computer (ADC), and the global positioning system (GPS), provided aircraft attitude, rate, airspeed, altitude, and position information to the FCC. The FCC processed these inputs through a set of control laws to determine the flight control actuator movement required to effect the current guidance command.

The actuator drive unit (ADU) monitored and controlled the movement of the appropriate electronic actuators. All flight control surfaces and the rotor blades were controlled by an electronic actuator - jack screw arrangement. The rotor disk could be moved collectively as well as tilted separately

TO WHOM IT MAY CONCERN:

Here is a copy of Professional Papers written by various people here at the Naval Air Warfare Center Aircraft Division. It was requested that a copy of each of the professional papers be sent to DTIC for retention.

If you have any questions, please contact Dorothy Reppel, 326-1709 or (301) 826-1709.

P.S. All the enclosed papers have been cleared for public release.

Accession For	
NTIS GRA&I	☑
DTIC TAB	☐
Unannounced	☐
Justification	
By	
Distribution/	
Availability Codes	
Dist	Avail and/or Special
A-1	

in the longitudinal direction. Lateral control was conducted through differential collective. All rotor and control surface actuators, as well as the ADU, FCC, IFMU, ADC, GPS, and DCPA incorporate redundant safety features designed to minimize the chance of aircraft loss, should a failure occur in one of the primary components. The flight control system was designed to automatically detect and isolate many types of system failures. However, if the two channels of the flight controls were in disagreement, and the system could not automatically isolate the problem, the internal pilot (IP) could manually disengage the defective portion of the flight control system, allowing the vehicle to return home for a safe landing. Photographs of the TRUS air vehicle inflight are presented in figures 1 and 2. A three view drawing and isometric view of the TRUS vehicle is presented in figures 3 and 4.

MODIFICATIONS TO SECOND AIRCRAFT

During the final landing of flight #6, on July 16, aircraft number 1 crashed. Although most of the major aircraft components survived the accident and were later installed and flown in ship 2, the aircraft structural damage prohibited further use of the vehicle shell. As a result of the accident investigation, aircraft # 2 incorporated several modifications that significantly enhanced the flying and handling qualities of the TRUS. The cyclic actuator rate was tripled from 14 deg/sec to 40 deg/sec. The cyclic authority was increased from 10 to 11.4 deg by improving the mechanical clearances. One FCS computer time frame delay (0.02 sec) was eliminated in the IFMU control feedback loop, resulting in 8 deg less phase at 1 Hz. The elevator motion was fixed at 5 deg trailing edge up position for airspeeds less than 30 kts. This was designed to reduce the elevator moment contribution in ground effect. The nacelle wheel stabilizing gear angle was reduced from 15 to 5 degrees forward, in an effort to minimize the loads imparted c~ the conversion actuators during landing. Finally, the rear main gear was re-mounted to the aft portion of the wheel well, extending the longitudinal footprint by 21.45 inches in order to better distribute the landing loads on the main gear and reduce the tendency for a tail strike. A black and white payload camera was installed in the nose of the aircraft as a way of providing the flight test team with an airborne view of the air vehicle attitude and rates during up and away flight testing.

DESCRIPTION OF GROUND CONTROL STATION (GCS)

The ground control station was a prototype of the GCS 3000, a system developed by Israel Aircraft Industries (IAI) for the Hunter Joint Tactical UAV (formerly the Short Range UAV). The GCS operated on 220 volt external power and included a backup internal battery system. The battery backup was designed to provide approximately one hour of GCS use in the event the primary external power was lost. The TRUS GCS required a minimum of two people to operate the system, an external pilot (EP) and an internal pilot (IP). The EP controls the air vehicle during takeoff, landing, and flight within visual range. The IP, positioned inside the GCS, is responsible for engine starts and shutdowns, beeping of the rotor rpm (N2), selection of the data link antenna, and controlling the TRUS when the aircraft is beyond visual range. The transfer of control between EP and IP was accomplished with a switch inside the GCS. All pertinent aircraft information was displayed near real time to the IP on a 19 inch color video monitor. The ground data terminal (GDT) provided the primary C-band uplink and downlink with the aircraft. The GDT was an antenna system comprised of both omni-directional, and directional auto-tracking antennas. The omni C-band antenna was used during the flight operations when the aircraft was within two miles. When the aircraft is operated at extended ranges, the directional antenna can be engaged, which was designed to be used at a range up to 40 nm. An UHF omni acted as a backup uplink in the event the primary C-band uplink failed, although in the prototype system tested, the backup was not truly independent of the C-band. The UHF was designed to have an effective range of approximately 30 nm. Switching from the primary to the backup uplink was accomplished automatically by the system if and when required. Switching can also be accomplished manually as needed. A photograph of the IP working inside the GCS and a schematic of the control system are presented in figures 5 and 6, respectively.

DESCRIPTION C GHT CONTROLS

During the TRUS demonstration, the external pilot (EP) controlled the vehicle while in flight. The flight controls for maneuvering the aircraft closely resembled those used by remote control model enthusiasts and functioned as an attitude controller. The flight control system had an inherent latency of 190-200 milliseconds which was twice as much as a typical manned aircraft. The external pilots trained in an Evans and Sutherland domed based simulator where the anticipated latency was incorporated. As buildup to flight testing, a short study was conducted with latencies ranging from 100 to 1000 milliseconds to investigate the controllability of the vehicle. The EP found that the 200 millisecond delay was acceptable, and appeared to have no problem maneuvering the computer model of the vehicle inside the dome simulator. During the actual flight demonstration, the inherent system latency did not appear to effect the handling qualities of the TRUS vehicle.

There were three flight control boxes; a primary external control box, a duplicate student box, and a backup control box located inside the GCS. All three boxes were hardwired to the GCS by way of a three hundred foot long cables. The length of cable allowed the EP to optimize his piloting location based on wind direction and the position of the sun in the sky. The EP stood behind a Lextan shield for protection when the air vehicle was in the immediate vicinity of the pad, otherwise the external pilot was free to move about the pad area. Through use of the two small control sticks located on the top of the flight control box (FCB), the EP was able to transmit directional, vertical, longitudinal and lateral commands to the aircraft. In addition to the primary controls, the FCB also had switches to command the nacelle conversion angle, the link loss mode, the raising and lowering of the landing gear, and one of three augmented flight modes. A diagram of the flight control box is presented in figure 7.

During the flight demonstration, several modes of augmentation were tested and verified. From the control box the pilot was capable of selecting one of three modes; ground, normal, and auto hover. Although the TRUS vehicle was initially flown in Ground mode, as testing progressed, this least augmented mode was used primarily for ground handling while the rotors were turning. Normal mode incorporated additional automatic compensation and reduced the pilot workload during the helicopter phases of flight. Auto hover mode, an inertial velocity controller, established the aircraft in a stabilized hover with respect to the air mass.

The three other modes were evaluated during phase III, turn coordination, conversion, and airplane mode. These modes were dependent on forward airspeed and had software protected gates which prevented the initiation of these modes under the wrong flight conditions. Turn coordination, which assisted the pilot during banked turns, began to phase in at 20 kts and continued through the full range of forward airspeed. At speeds above 30 kts the directional stick was disabled and the function was combined with the lateral stick input. Flying with turn coordination off at airspeeds less than 30 kts, resulted in sideslips up to +/-45 deg. Conversion mode, which was initiated when the nacelles were between 80 and 0 deg, established an airspeed cooridor of +/- 10 kts which limited the airspeed authority of the EP. In airplane mode, the rotor speed could be beeped down from 100% to 80% rpm in order to improve rotor blade efficiency and reduce aerodynamic loads in forward flight. A matrix of the flight control box functions are presented in figure 8.

EMERGENCY MODES OF OPERATION

RETURN HOME AND TAKEOFF- LAND MODES

The aircraft system was designed to respond in one of two ways in the event that both the primary and backup data links were lost. The first was the return home mode, and the second was takeoff - land mode. The EP selected which mode to engage from the flight control box based on where the vehicle was in the flight profile. When the return home mode was selected, and both the primary and secondary uplinks to the aircraft were lost, the FCC was designed to activate the "return home" program approximately two seconds after link loss occurred. The return home program was designed to command the air vehicle to fly toward the launch point using a way point previously loaded into the FCC prior to takeoff. When the aircraft came within a defined range of the way point, the embedded program would command altitude and airspeed reductions and eventually, pylon conversion to helicopter mode. Once in helicopter mode, the vehicle was designed to establish a hover at approximately 100 ft AGL, and after a predetermined amount of time, if uplink was not re-established; enter a vertical descent until touchdown. The mode was designed to optimize the chances of re-establishing uplink during the programmed maneuver. If uplink was established during the automatic sequence, the return home mode would be canceled and the aircraft would once again be under control by the EP or IP. In the immediate vicinity of the pad or landing area, takeoff - land mode was usually selected. If loss of uplink occurred when in this mode, the software was designed to bring the aircraft into a stable hover, and if link was not re-established after a preset time, the air vehicle was programmed to descend until touchdown was accomplished.

FUTABA BACKUP CONTROLLER

The TRUS vehicle FCC had the capability to accept guidance commands from a backup hand held Futaba radio control transmitter that was kept within easy reach of the EP during all flight operations. Futaba is a brand name for the commercially available radio model plane system used for this purpose. The Futaba controller was designed to be utilized in the event that the air vehicle entered loss of link mode, and the primary and secondary uplinks could not be re-established. Within one thousand meters of the EP, the Futaba could have been used to regain manual control. As a safety precaution, the FCC logic was programmed to ignore the Futaba commands unless both C-band and UHF uplink communication had been lost. The Futaba system was ground tested to verify the control response link with the air vehicle prior to the first flight of each aircraft.

FLIGHT TERMINATION SYSTEM

The TRUS air vehicle was equipped with a *flight termination system* (FTS) which when activated, would shut off the fuel supply to the engine and was designed to then command the aircraft in a steep descent. The FTS consisted of an independent ground based transmitter which sent a discrete signal to the matched airborne receiver which was designed specifically for the purpose of flight termination. The effective line of sight range of the FTS was conservatively estimated to be 50 nm. The FTS would have been used in the event of a catastrophic system failure, or if uplink with the vehicle was lost and the aircraft appeared to be a public hazard. Since the FTS button was located in the GCS, the flight test directors were responsible for giving the verbal command to terminate the aircraft.

DESCRIPTION OF FLIGHT TEST PROGRAM

Extensive ground testing was conducted at the Bell Helicopter plant in Hurst, TX. These test included gearbox checkouts, conversion verification with and without the rotor blades attached, track and balancing and "green run" of the aircraft. A green run is defined as a ground run and inspection of the vehicle systems prior to signing it off as flight worthy. After the incident involving the first aircraft, the second vehicle went through "green run," followed by several hours of air wake study and analysis.

The flight test program was originally envisioned to be a sixteen week, forty hour effort., Unfortunately, due to the loss of the first aircraft, budget constraints, and schedule slips, the flight testing was ultimately reduced to a helicopter mode test period lasting a little over a month, and a four week conversion test period that was extended an additional two weeks for a total of ten weeks. With the decrease in test time available, the demonstration program was redefined with the primary goal being converting the aircraft to airplane mode and flying in excess of 150 kts.

FINALIZED TEST PROGRAM AND OBJECTIVES

After the accident involving ship # 1, the test program was redefined into three distinct phases. The objectives of each phase had to be accomplished prior to initiation of the next level of testing. This three phase plan proved to be a sound approach and ultimately led to the successful completion of the program.

PHASE I OBJECTIVES (GROUND RUNS AND SYSTEM VERIFICATION):

(1) Verify powertrain and lubrication system operation for at least two hours, including high power and high rotor rpm conditions.
(2) Measure tail dynamic pressure in ground effect.
(3) Verify instrumentation system.
(4) Verify control hand-off procedures between the external, student, and internal controls and the Futaba backup system.
(5) Verify flight termination system operation.
(6) Perform intersystem electromagnetic compatibility checks.
(7) Verify rotor actuator operation.

PHASE II OBJECTIVES (HELICOPTER MODE TESTING):

(1) Verify control system gains and aircraft stability in hover.
(2) Assess aircraft low speed controllability.
(3) Demonstrate the following:
 Left and right lateral translations.
 Forward and aft translations.
 Vertical climbs and descents from a hover.
 Controlled and predictable, takeoffs and landings both with and without the training gear installed.
 At least one power recovery from a descent.
 Hover turns over a spot.
(4) Measure hover performance in ground effect (IGE) and out of ground effect (OGE).
(5) Verify operation of Normal and Auto Hover modes.
(6) Establish an initial helicopter flight envelope and control/trim requirements.
(7) Electromagnetic Interferance (EMI) testing in preparation for operating on YPG range.

PHASE III OBJECTIVES (CONVERSION AND AIRPLANE MODE TESTING):

(1) Verification of established helicopter flight envelope and conduct a systems check flight.
(2) Conduct initial figure eight and racetrack pattern work in preparation for conversion testing.
(3) Verify operation of turn coordination, conversion, and airplane modes.
(4) Conduct incremental conversion testing from 90 to 0 deg nacelle.
(5) Conduct controlled flight in Airplane mode.
(6) Reduce Nr from 100 to 80 % while in airplane mode and increase forward level flight speed from 135 to above 150 kts.
(7)* Train student pilot to take over as new EP.

* Although this was not an original requirement, it became a necessity as the primary EP left during the Phase III testing.

TECHNICAL CHALLENGES

LOSS OF AIRCRAFT #1

During the final landing of flight test 6, on July 16 1993, aircraft #1 underwent large pitch oscillations resulting in the tail striking the ground and the aircraft coming to rest inverted. Fortunately there were no injuries and the air vehicle remained fairly intact with the exception of the aircraft structure. An investigation was conducted during a three week period following the accident. The primary black boxes, and mechanical components including the transmission and engine were inspected. The post flight inspection of the aircraft revealed that all components were functioning properly and that no mechanical failure contributed to the accident. After bench testing and calibration of the major electronics, and breakdown and inspection of the engine, many of the components with the exception of the drivetrain and gearboxes were eventually used in aircraft #2. The accident investigation concluded that during the final landing, the aircraft received a large pitch disturbance. The resulting aircraft pitch attitude response was large enough to demand more pitch control actuator throw than was available. With the actuators ineffective the aircraft lost control and the pitch attitude increased until the crash. Based on the findings of the investigation, several changes were incorporated in aircraft #2 before testing resumed. These modifications were previously described above in the paragraph "Modification to second aircraft."

The analysis of the accident was hampered by the fact that the there was no instrumented data during the initial excitation. The primary instrumentation system had been turned on to record the landing but too late to capture the initial small perturbations on the data tape. As a result, the primary data source for the investigation was the video tape footage of the entire event. Had a backup data tape been recording the entire flight, the data could have been used to determine the cause of the accident. Based on analysis of the events leading up to the accident, one of the recommendations for further TRUS testing was to have a back up recording of the entire flight from start up to shutdown in case another incident occurred. An analog tape unit was installed in the instrumentation van for the follow on testing with aircraft #2 and was used on each subsequent ground and flight test. In addition to the continuous backup data tape, a video record was made of the aircraft #2 flight testing when the TRUS was within one mile of the pad.

FLIGHT TESTING OF THE TRUS

The aircraft appeared to be easily controllable by the two external pilots. It is interesting to note that both pilots had over ten years of radio control model experience. The first external pilot had both private and helicopter licenses. The second external pilot was working on his helicopter rating, and was previously a navigation officer on a P-3 in the navy. The pilots flew the aircraft externally, with no visual cues with the exception of watching the vehicle in the air. The external and backup pilots wore headsets where they were updated by the test team on applicable control positions and aircraft attitudes. The communication network was two way, with the external pilot having the capability to request information which might assist him in flying the vehicle. Safety of flight concerns such as engine chip indications and structural load limits were relayed to the external pilot by the IP which was monitoring the health indicators and mission related parameters from inside the GCS.

At speeds in excess of 30 kts, the external pilot established either a standard "race track" or "figure 8" pattern. The pattern was established between 400 to 600 ft AGL at pilot's discretion and was designed to keep the aircraft within visual range. The pilots had a tendency to favor the figure 8 pattern since it allowed for both right and left hand turns and kept the vehicle closer to the pad area on the straight and level legs when control response testing was conducted. The patterns lengthened with increasing airspeed. At speeds higher than 60 kts the aircraft strobe was turned on in order to maintain visual track on the vehicle during the turns when the TRUS was farthest away. At the maximum airspeed tested of 160 kts, the pattern, centered about the launch and recovery area, and was approximately 4 miles long and 1.5 miles wide.

When the aircraft was up and away, approximately 400 ft AGL, 20-30 kts, it was difficult for the EP to ascertain the precise spatial orientation of the vehicle. During the initial pattern work, the pilot was unaware that the vehicle was in a 45 degree sideslip. In an attempt to give the pilot additional information, the video signal from the onboard nose camera was patched out to the EP. The nose camera provided a real time picture of the aircraft attitude and a sense of rate (a pseudo cockpit image). Unfortunately, the nose camera video image was black and white and the glare on the monitor from the sun effectively washed out the image making it of little value.

Classical flight tests requiring proprioceptic cues, such as maneuvering stability could not be conducted since the EP was flying the TRUS from outside the aircraft. The EP had to rely solely on his visual perception of changes in aircraft attitudes to sense motion. Certain flight conditions, such as whether the aircraft was straight and level, were difficult for the EP to judge at altitudes above 100 ft without verbal updates from the flight test director or IP. Control response testing was an interesting evolution since the EP was not a trained test pilot. The type and quality of the inputs were described and rehearsed on the ground in the flight simulator prior to the phase II testing. Step and doublet inputs were performed in all axis to establish controllability of the vehicle. Although a control fixture was not used, the lightness and size of the controls allowed the EP to calibrate the magnitude of the desired input after coaching over the headphones by the test director. The EP eventually calibrated the control sticks and after some practice, was able to command fairly consistent control inputs throughout the remainder of the test program. A plot of typical control response data is presented in figure 9.

During the phase III testing the primary external pilot had to be replaced by the backup or student pilot. The transition was made over a two week period with portions of three flights dedicated to pilot training totaling an hour of "stick time." Under the tutelage of the primary pilot, the student pilot was capable of flying the air vehicle independently. After the original EP left, the new EP flew the last three demonstration flights without any problem. Even though the student pilot had only fifteen hours of TRUS simulator time before arriving to the test site, training the new external pilot to take over flight test operations occurred quickly. The new EP commented that it was easy to learn how to fly the TRUS air vehicle since the system had several levels of sophisticated augmentation. A photograph of the external pilot flying the TRUS is presented in figure 10.

C-BAND ISSUE

For the TRUS demonstration, the contractor attempted to show compatibility with the Short Range UAV system by using a similar ground station subcontracted by IAI; the ground control station developer for the Hunter Joint Tactical UAV, (formerly Short Range UAV). During the helicopter testing at the Globe facility outside of Fort Worth, TX the quality and reliability of the C-band system was a major concern. Precautionary landings were conducted during three flights after the loss of the primary C-band datalink. IAI had difficulty trouble shooting the problem, citing initially that the airborne equipment might be too cool. Several of the components were swapped out in an attempt to resolve the problem to no avail. After several days of trouble shooting the system, Bell engineers determined the problem may have been a result of the IAI equipment design. It was discovered that the downlink and uplink signals were destructively interfering with each other. The fix involved removing an amplifier from the downlink signal. This appeared to solve the problem.

For the YPG conversion and airplane mode testing, a nose mounted fixed forward payload camera was installed not only to give the test engineers an indication of the attitude and rate of response of the air vehicle, but also to assess the quality of the data link. Since the downlink was weaker than the uplink as a result of removing the amplifier, a degradation of the signal quality of the nose video acted as a warning that the up link signal may also soon be effected. During the final flights conducted primarily in airplane mode, the signal quality of the downlink video became increasingly more intermittent using the omni antenna. Although it is unclear whether antenna blanketing was a factor, the maximum range flown away from the ground based GCS was around 3 miles. Use of the directional antenna improved the signal quality, but required the full attention of the IP in order to maintain a track of the aircraft diverting his attention from more immediate concerns such as monitoring aircraft warning indications. For future, extended range tests of the TRUS vehicle using the C-band datalink, it is recommended that improvements be made to the system and validated by the Government in order to ensure the safety of the aircraft. Also, an investigation of the Short Range system should be conducted to see if improvements to the production version have been made which were not incorporated in the TRUS GCS test system.

GPS ISSUE

The TRUS vehicle used a commercially available, CA-code, four channel GPS receiver as a source for position data for use by the IFMU's. As a cost savings measure, Bell decided to use the existing 3-dimensional software already incorporated in the integrated flight management units (IFMU's), which required four satellites in order to obtain a solution. During the first series of tests involving aircraft #1, the IFMU's were reporting an invalid GPS signal even though the satellite prediction program indicated that there were sufficient satellites available in order to obtain a solution. This situation persisted on and off throughout the testing of aircraft #1. Later, while trouble shooting the system during the ground runs with aircraft #2, the GPS system dropped out unexpectedly on several occasions. This led to an investigation which indicated that the acceptable position dilution of precision (PDOP) values of the GPS system (8) and the IFMU (4) were different. A software change in the IFMU's to accept the higher PDOP value improved the situation but did not definitively solve the problem. In order to continue on with the flight test evolution it was decided to conduct a precautionary landing if the GPS signal was lost.

During phase II, the problem was intermittent with possible causes being attributed to satellite signals being blocked by the aircraft hangar and other surrounding structures near the flight test area. The GPS almanac was used during the helicopter test pl...: to a greater extent in order to predict down times when four satellites might not be available. The problem persisted throughout the Phase II portion of the demonstration, resulting in flight test delays and up to six cancellations. On two occasions there was evidence of possible interference by GPS constellation system testing which was occurring independent of our effort. A back up GPS system was used to verify the quality of the aircraft GPS signal received with varying degrees of success.

While conducting the phase III portion of the TRUS demonstration program, GPS problems intermittently continued. A spare GPS receiver was swapped out for the unit in the aircraft which improved the GPS reliability. Bell believes that the GPS signal problems will be resolved if they change the software requirement from 3 to 2 dimensional. The TRUS system has both barometric and radar altitude sensors and doesn't use the altitude parameter given by the GPS receiver for navigation, so incorporating a 2 dimensional data solution may resolve this issue.

RESULTS OF TESTING

A flight demonstration history is presented in figure 11.

PHASE I:

The phase I objectives were achieved slightly behind schedule but there were no surprises. The tail dynamic pressure was measured at two locations at approximately eight feet AGL with respect to the rotor height and with the aircraft tied down simulating the aircraft turning on the ground. A sensor attached to a robotic arm sampled the airflow coming off the back of the tail with rotors at 100% rpm from various heights both above and below the horizontal tail. The groundwash dynamic pressure appeared within reasonable limits of what was estimated and the aircraft was allowed to proceed onto the next phase of the demonstration.

PHASE II:

The phase II objectives were achieved during 8 flights totaling 2.0 flight hours. As a result of the significant modifications to aircraft #2, both mechanically and to the software based on the aircraft #1 accident, the initial TRUS flight envelope had to be re-established. Since the saturation of the pitch control actuator was the primary contributor to the accident, a significant portion of phase II testing was dedicated to validating the new actuator control. Additional control response tests were conducted in all channels starting from a hover and building up to translational flight to verify that there were no other control saturation problems with the other actuators.

The flight control maneuvers were predictable and repeatable. The EP quickly adapted to the flight controls and was able to perform vertical climbs and descents as well as lateral and longitudinal translations as commanded, anticipating when to roll out at the desired condition. Hover turns on the spot appeared to be easy to establish and maintain. Although some drifting did occur during hover turns, this could be attributable to pilot technique instead the vehicle itself.

The aircraft was predictable in a hover with either normal or auto mode engaged requiring minimal inputs from the EP to maintain the aircraft within +/- 1 ft in all directions over a designated spot. Inputs to maintain position were of the order of one every two seconds. In winds of less than 5 kts the vehicle required fewer inputs sometimes as few as one every five seconds. The Allison C-250 engine mounted in the TRUS provided ample power for both IGE and OGE hovers on moderately hot days, in outside air temperatures up to 26.5 deg C.

By the time of the phase II exit criteria flight, after adjustments to the control system gains, the control response was deadbeat in the lateral, longitudinal, and vertical channels. The TRUS system was ultimately designed to fly without pilot intervention, therefore having a deadbeat control response after applying a pilot input was desirable. A sample control response input plot from phase II is provided in figure 9.

After the optimal control gains had been established, Normal Mode and Auto Hover testing went rather smoothly. These enhanced modes made the aircraft easier to fly and may be of significant value in the future if this vehicle is to some day incorporate an auto landing system for shipboard operations. A summary chart of the flight envelope at the end of phase II is presented below.

TRUS Flight Envelope after Phase II

Maximum altitude attained:	120 ft AGL
Maximum fwd speed:	20 kt
Maximum aft airspeed:	10 kt
Maximum lateral speed:	10 kt
Vertical climbs and descents:	+/- 500 fpm
Maximum wind speed flown in:	15 kt
Directional turn rate:	35 deg/sec

Ground mode, normal mode, auto hover mode: verified, acceptable for flight operations.
Flight can be conducted without training gear.

PHASE III:

The phase III objectives were achieved over a six week period at the Yuma Proving Grounds (YPG), AZ during eleven flights totaling 8.42 flight hours. The isolated desert range provided optimal weather and location to conduct the conversion and airplane mode testing. During this time of year Yuma has a pleasant climate, with clear skies and moderate temperatures, although wind was occasionally a factor.

The test proceeded methodically, gradually converting the aircraft nacelles forward initially from 93 to 77 deg in three degree increments, then from 70 to 20 deg in ten deg increments, with final conversion testing conducted at 15 and 0 deg nacelle angles. At each new condition, race track or figure "8" patterns at the new conversion angle were conducted to assess controllability. Primary data records were collected during straight and level, banked turns to the right and left, and forward flight climbs and descents before proceeding on to the next conversion angle. Once the data from the previous flight had been analyzed, the flight test proceeded by further increasing the conversion angle forward, ultimately to the stops, or zero nacelle angle: airplane mode. Once the flight envelope was established for the zero deg nacelle, airplane mode condition, the rotor rpm was beeped down from 100% to 80%. This was conducted in an attempt to increase the rotor blade efficiency and reduce the acoustical noise signature. Once the vehicle was stable at 135 kts, 80% rpm, the EP commanded forward stick to increase the level flight speed in ten knot increments out to approximately +160 kts. Primary data records were collected during straight and level, banked turns to the right and left, and forward flight climbs and descents at each airspeed before proceeding on to the next data point. A summary chart of the flight envelope at the end of phase III is presented below.

TRUS Flight Envelope after Phase III

Maximum altitude attained:	820 ft AGL
Maximum fwd speed:	+160 kt, at 80 % rpm (actual speed TBD)
Maximum aft airspeed:	10 kt
Maximum lateral speed:	10 kt
Vertical climbs and descents:	+/- 500 fpm
Maximum wind speed flown in:	15 kt
Directional turn rate:	35 deg/sec
Nacelle range:	93 to 0 deg
Maximum angle of bank:	+/- 50 deg

Turn coordination, airspeed mode, conversion mode, and airplane mode: verified, acceptable for flight operations.

ENHANCING CHARACTERISTICS

THE TILT ROTOR TECHNOLOGY

The TRUS program successfully demonstrated that tilt rotor technology is a viable design concept for a future production UAV. A TRUS like vehicle has the ability to takeoff and land from a confined area. In preparation for proof of this requirement, a 24 ft circle representing the landing circle on board small combatants was painted on the YPG tarmac at site 8A where takeoffs and landings were conducted. For takeoffs, the aircraft was prepostioned in the center of the circle prior to startup and ascended vertically to an altitude of approximately two hundred feet before preparing to transition to forward flight. The external pilot could consistently, manually land the aircraft into the target circle at varying wind conditions with minimal effort required. The advantage of staging a UAV out of a small confined area is not unique to the shipboard environment. In the ground combat environment, the vehicle may not require a launch and recovery area much bigger than a 30 ft circle of improved surface and could easily stage out of either parking lots or small roads. A TRUS type vehicle does not require the use of a rocket assisted take off (RATO) system as many other UAV's in its class do, there by reducing the ground handling procedures, as well as the thermal image signature a RATO launch presents to possible hostile forces during the takeoff sequence.

The tilt rotor technology takes two advantages; launch and recovery from a confined area, and dash speed of a fixed wing type aircraft and combines them into one vehicle. The TRUS has a proven forward flight airspeed of +160 kts and may be capable of level flight speeds in excess of 190 kts. This type of speed advantage allows a tilt rotor UAV to get to the mission area quickly and spend more time on station doing its job, which is currently envisioned to be intelligence gathering or laser designating. Also, the faster flight speed of the tilt rotor could decrease the UAV's susceptibility to being shot down by small arms ground fire when compared to slower moving, purely helicopter vehicles. The tilt rotor technology is a viable concept for both a ship based and forward deployed UAVs and should be incorporated into future force structure plans.

AIRCRAFT CONTROLLABILITY

The heart of the TRUS demonstrator was a highly augmented flight control system which simplified the task of flying the aircraft for the external pilot. The quality of this augmentation system appears to have been optimized over a broad range of flight conditions. Modifying the flight control system handling qualities was accomplished primarily by incrementally fine tuning the gains in each distinct channel. By the end of the flight program, the TRUS vehicle flight control system appeared to operating "right where it should be," and a possible production vehicle of this type would most likely resemble the handling qualities of the vehicle tested for this weight class. The relative ease of flying the TRUS vehicle was demonstrated when the backup pilot was able to take over the full responsibilities and control of the TRUS test vehicle after only three flights and just over an hour of hands on flying of the demonstrator vehicle. The most challenging aspect for the student pilot to master was the sensitivity of the control sticks on the FCB. The flight control gains had been "tuned" to the first pilot's flying style, and the second pilot tended to be slightly more aggressive on the controls. The new EP compensated for the sensitivity by making the control sticks on the FCB longer and by adjusting his flying style to be more in line with the inherited control system. As previously stated, the new EP was able to master the flight controls within three flights and flew the first flight conversion to airplane mode with relative ease. The degree of stability and augmentation incorporated into the TRUS flight control system should make it relatively easy to incorporate an auto launch and recovery system, such as the common automatic recovery system (CARS) which is one of the proposed candidates for UAV shipboard operations.

PERFORMANCE

When compared to other UAV power plants currently in use or being developed, the choice of the Allison 250-C20B gas turbine appears to have been a smart decision. The engine flown in the first vehicle which crashed on flight six was inspected, put back together and later replaced in aircraft #2 and used for the duration of the flight test program. The Allison 250 is a proven engine with years of maintenance documentation, and has been flown in several types of helicopters both civilian and military for literally millions of hours. With the exception of the two precautionary landings conducted after engine chip detection, the engine was reliable and appeared to require little if any maintenance. Lab analysis of the first engine chip determined the material was machine grade iron used during the manufacturing process and was not part of the engine itself. The second engine chip detected turned out to be a hair like piece of metal which just barely made the electrical connection which set off the detector. If a fuzz burner was incorporated into a production version of a TRUS like vehicle, this problem would most likely be eliminated. In both chip detection cases, ground runs were conducted after which no additional contaminants were found, and the test program resumed without any further incidence.

Using a production helicopter engine in a UAV has another distinct advantage; the engine burns a wide range of fuels. One of the current concerns with other UAV powerplants is the burning of fuels other than what is readily available in either a shipboard or typical combat fuel farm environment. The Allison 250 engine can burn JP-5 which is readily available on most ships or JP-8 which is a standard army fuel available in the field. The engine can also burn other fuels available on an emergency basis if the need arises. Using the engine currently incorporated in the TRUS reduces the logistics and ground handling safety issues involved with non typical military fuels thereby increasing safe operations in a mission type environment and ensuring that the fuel is available out of multiple staging areas that typically support aircraft flight operations.

The engine/airframe matching for the TRUS demonstrator appears to be favorable. At no time during the testing did the aircraft appear to be power limited. Climbs and descents were easy to initiate and maintain. Since determining the maximum climb rate of the TRUS demonstrator was beyond the scope of the test, this parameter has yet to be determined. Although climbs rates of up to 500 fps appeared to be effortless for the engine. Use of the Allison C-250-C20B in the TRUS air vehicle was an enhancing characteristic and the approach of incorporating a proven multi-fuel engine should be investigated for a production maritime UAV.

PRIMARY SYSTEM REDUNDANCY

The dual redundancy of the TRUS vehicle primary control systems was an enhancing characteristic. During the Phase II testing there were three instances where the primary, C-band data link failed and reverted to the backup UHF data link. Had the UHF data link not been available, the aircraft would have entered loss of link mode and the Futaba secondary backup would have been attempted. During flight 11, the channel A air data computer (ADC) failed while the aircraft was in a 70 ft AGL hover, the IP switched from dual ADCs to selecting the good; channel B ADC. The EP then conducted an uneventful landing. Had the dual channel ADC not been available, the aircraft would have most likely crashed. The pilot control box (PCB) was triple redundant so in case something happened to the primary pilot or primary PCB, the student EP or backup PCB could be used to land the aircraft. In a worse case scenario, if the primary and backup PCB's both failed, the IP could then take control of the vehicle and land the aircraft from within the GCS. The dual redundancy of the control surface and rotor system actuators allowed each system to share the control load thereby reducing the chances of exceeding the control authority of one actuator. Also if one actuator failed, the control systems were designed such that the remaining good actuator could handle the predicted loads. Having at least dual redundancy on the TRUS vehicle primary systems significantly reduced the risk to the aircraft and saved the vehicle from being damaged on at least four separate occasions. The dual redundancy of the flight control actuators and primary systems is an enhancing characteristic and should be incorporated in all future designs of production type UAV's.

STABILITY OF PLATFORM

An airborne black and white camera was mounted under the nose of the aircraft to provide additional visual data to the test team. The real time video signal from the non slewable camera was transmitted on the downlink where it was then split off from the GCS to several monitors at the test site. Flight # 9, which was the first time the nose camera was used in flight, presented a slightly shaky image when the aircraft was airborne. After flight #9, the vertical azimuth of the camera was adjusted slightly up and the mounting hardware was tightened. From flights ten through nineteen the image was stable and with the exception of ground run up, provided an acceptable picture. The nose video camera provided additional evidence that the TRUS air vehicle was stable in all regimes of flight conducted. Flight test engineers could easily determine the attitude and relative rates of the aircraft by observing the payload camera. There were at least two incidences where the nose camera image gave indications of flight disturbances which were not initially apparent on the strip chart recorders. The terrain features were easily discernible on the video, and the stable image assisted the IP in determining precisely where the vehicle was over the range. A mission payload flown aboard a TRUS type aircraft would not require gyro stabilization which would reduce the weight and the complexity of the airborne package.

MODULAR DESIGN OF THE NOSE SECTION

The nose section of the TRUS aircraft housed a majority of the electronic systems. During flight, the nose section was held in place by several hinged fasteners. After a flight or while performing maintenance, the nose section could be opened up in less than a minute and provided easy access to most of the electrical boxes onboard the aircraft, thereby making trouble shooting and system checks a relatively simple task. For an operational vehicle, the TRUS nose modular design approach would allow for the concept of several different interchangeable payloads which could be fitted to the aircraft depending on the mission requirements. The modular design would also allow a maintenance team to quickly swap out a malfunctioning unit in a minimal amount of time. The TRUS detachable nose concept is an enhancing characteristic which should be incorporated in future production UAV systems. A photograph of the TRUS modular nose design is presented in figure 12.

LESSONS LEARNED

THIS IS A DEMONSTRATOR VEHICLE

Although the TRUS flight demonstration was a successful program, the vehicles tested were not intended to be used in an operational environment. In order to meet the deadlines and the program cost constraints the two demonstrator vehicles were "quick builds." Although the vehicles were structurally sound, and designed to be flown for almost one hundred hours each, there was no attempt to weatherproof the TRUS or incorporate features which would allow the aircraft to be deployed in a maritime environment for more than a month. This is not to say that the design itself could not be adapted to produce an all weather, operational vehicle. The information obtained during the construction and testing of the TRUS demonstrator vehicles will be useful in designing a production version of what was evaluated. With some primary modifications, the vehicle tested could be turned into a viable fleet asset. A production vehicle would most likely use autoclave cured composites instead of room temperature lay-ups to make the structure more resilient for the mission environment. Significant weight savings could be attained by using specifically designed cast gearboxes and mechanical components, as well as optimizing the primary electrical systems for use in a TRUS type UAV. With these type of improvements, the performance of a follow-on pre-production prototype vehicle would be similar and probably better than the demonstrator air vehicles built for this program.

THE GCS

The TRUS air vehicle system tested appeared to be portable and have incorporated the latest developments in technology with the exception of the GCS. The ground control station used for the demonstration, although a prototype version, closely resembles in size and operability characteristics of the production Hunter Joint Tactical UAV GCS system. The GCS had to be transported to and from the test sites on a flat bed truck. The GCS required a significant amount of cooling in order to function correctly. The GCS internal cooling had to be modified prior to testing in order to ensure that the system would function correctly during the full range of environmental conditions anticipated.

The GCS container, the approximate size of a standard van, would be difficult to install on small combatants, and would take up a significant amount of hangar space if installed onboard ship. Also from an operational standpoint, placing the GCS inside a small combatant hangar which is one of the few places it could be installed, does not position the IP where he or she is of most benefit during mission operations, in the Combat Information Center (CIC).

During ground based operations, the current GCS represents the largest and heaviest part of the TRUS system. Although relocating the air vehicle to a new location could be achieved rather simply by flying the aircraft to the site, the GCS would be logistically more difficult to transition to a new operational area. In a modern battlefield environment, having to relocate a GCS the size of the one used during this demonstration would limit the effectiveness of the air vehicle to perform its mission. The GCS size and level of technology prohibit it from being easily incorporated on a small combatant and a better solution to this design problem is warranted. With the current electronic trend in laptop and microcomputers of increasing capability while at the same time decreasing in size, power requirements, it seems that there may now be a better, more portable alternative to the current GCS used for this demonstration. A photograph of the outside of the GCS is presented in figure 13.

THE GOVERNMENT/CONTRACTOR TEAM APPROACH

Although the concept of a joint government/contractor test team approach is not new, it certainly was an effective way of executing a flight demonstration program like TRUS. In the past, I have seen programs where it appeared that the Government and contractor teams lost sight of the fact that in the end they both desired the same thing, a safe and successful flight test program. Soon after the TRUS contract was awarded, both Bell and the Government realized establishing adversarial relationship was in neither parties interest. For two years the Government and the contractor, Bell Helicopter Textron have worked together in order to optimize the test program as well as reduce risks and cost. The process resulting in the successful TRUS flight demonstration ended up closely resembling a TQL process; where experienced people were brought in to solve problems and the team was disbanded when the program was finished. A TRUS development advisory group (TDAG) was established where key members from the Government and Bell test teams came together and discussed risk reduction, facility support requirements, flight test profiles, data reduction and analysis requirements. Although an evolving process throughout the effort, the TDAG met at least once a quarter prior to the demonstration to discuss program progress as well as resolve issues and concerns.

Later on, personnel from the Yuma Proving Grounds joined the TDAG in order to continue the process begun by the Navy and Bell. Ultimately, the constructive dialog established during this process led to a favorable working relationship between both parties, resulting in the accomplishment of the demonstration objectives at the lowest possible cost to the Government. The team approach enhanced data gathering and promoted informal dialog with the contractor where daily progress and delays were laid right on the table. The TRUS test program demonstrated it is in the Government's best interest to conduct projects of this type using a team concept as long as both sides maintain a fair and equal partnership.

THE FUTURE

ENVELOPE EXPANSION

Although the final objectives of the program were accomplished, and the utility of the tilt rotor concept for UAV was proven, the full potential of the vehicle has yet to be realized. The initial flight demonstration proposal included additional helicopter work, full development of the forward flight envelope and altitude performance testing up to ten thousand feet. Unfortunately these objectives were eliminated from the program due to time constraints and cost overruns. The full capabilities of the TRUS air vehicle should be investigated. Now that the aircraft has flown and the baseline handling qualities have been defined, future funding can be more specifically focused towards flight testing and envelope expansion. Since no real endpoints were reached during this program, the TRUS vehicle may be more capable than the current flight envelope has demonstrated.

VLAR

Bell Helicopter has submitted a proposal for the vertical launch and recovery program (VLAR) to be awarded in March or April of 1994. If Bell wins a contract for this program, this would be an opportunity for additional work to be dedicated towards investigation and expansion of the current TRUS flight envelope.

SHIPBOARD TESTING

To date, aircraft # 2 has only used ten to twenty percent of its designed airframe life span. After some additional follow on flight testing conducted in helicopter mode; primarily simulating launch and recovery approaches to a small combatant, the demonstrator vehicle could be tested aboard a small deck ship as part of a follow on feasibility study. This shipboard information would be valuable for further defining the requirements for a production type vehicle.

SUMMARY

The TRUS flight demonstration was a unique opportunity to evaluate a vehicle which incorporated both helicopter and turboprop design concepts. Since the operator or external pilot was not inside the vehicle, certain test techniques were viable while others had to be modified or eliminated. In the past, development of vertical launch and recovery unmanned air vehicles has been hampered by the lack of sophisticated flight control systems, or the trade off of dash and range capability by using a pure helicopter aircraft. The TRUS demonstration indicates these former technical challenges may have now been overcome. The tilt rotor technology takes two advantages; launch and recovery from a confined area, and the dash speed of a fixed wing type aircraft and combines them into one vehicle. The degree of stability and augmentation incorporated into the TRUS flight control system should make it relatively easy to incorporate an auto launch and recovery system, such as the common automatic recovery system (CARS). The TRUS has a proven forward flight airspeed of +160 kts and may be capable of level flight speeds in excess of 190 kts. The proven stability of the air vehicle means that a mission payload flown aboard a TRUS type aircraft would not require gyro stabilization which would reduce the weight and the complexity of the airborne package. With the Department of Defense facing decreasing budgets and the task of reducing the number of manned aircraft, TRUS type UAV's may provide a cost effective alternative. At eight hundred feet, and 2 miles from the launch the area, the TRUS vehicle could barely be seen without the use of the onboard strobe. At an operational altitude of two thousand feet or higher, a TRUS aircraft would be a difficult target to track by radar, thermally or acoustically. If an UAV crashes behind enemy lines, the primary result is the loss of the asset, there is no concern over repatriotization. You don't have to worry about sending in a SAR team to extract the UAV.

THE ALPHABET SOUP (LIST OF ACRONYMS)

AGL	above ground level
ADC	air data computer
ADT	air data transmitter
ADU	air data unit
CA-code	commercially available-code, as related to GPS
CIC	combat information center
DCPA	digital central processor assembly
deg	degrees
EMI	electromagnetic interferance
EP	external pilot
FCB	flight control box
FCC	flight control computer
FCS	flight control system
FTS	flight termination system
GCS	ground control station
GDT	ground data terminal
GPS	ground positioning system
IAI	Israel aircraft industries
IFMU	integrated flight management unit
IGE	in ground effect
IP	internal pilot
ITT	integrated test team
OGE	out of ground effect
km	kilometer(s)
kt(s)	knot(s)
Nr	rotor speed
PDOP	position dilution of precision
RATO	rocket assist take-off
rpm	revolutions per minute
SAR	search air rescue
TDAG	TRUS development advisory group
TQL	total quality leadership
TRUS	tilt rotor UAV system
UAV	unmanned air vehicle or unattended air vehicle
UHF	ultra high frequency
YPG	Yuma Proving Grounds

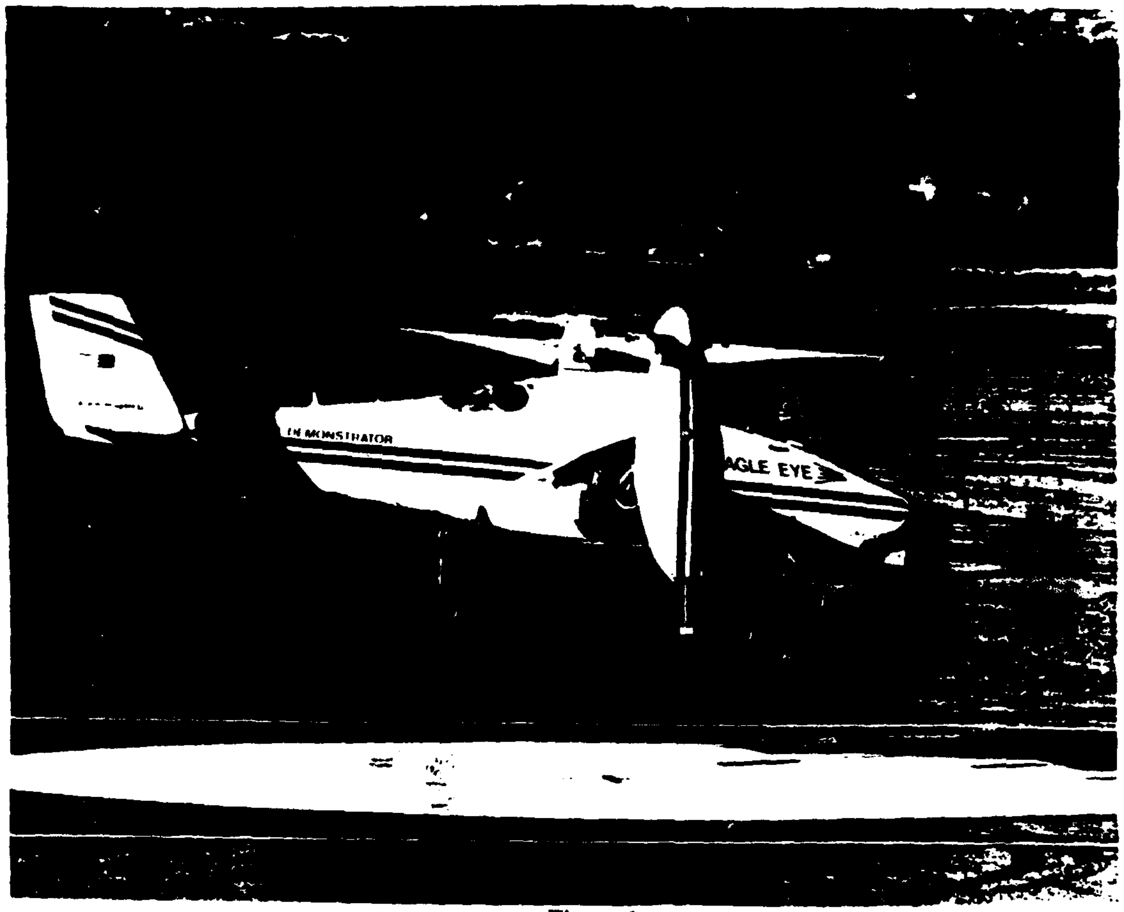

Figure 1
TRUS AIRCRAFT FLYING IN HELICOPTER MODE

Figure 2
TRUS AIRCRAFT FLYING AT 15 DEGREES NACELLE ANGLE

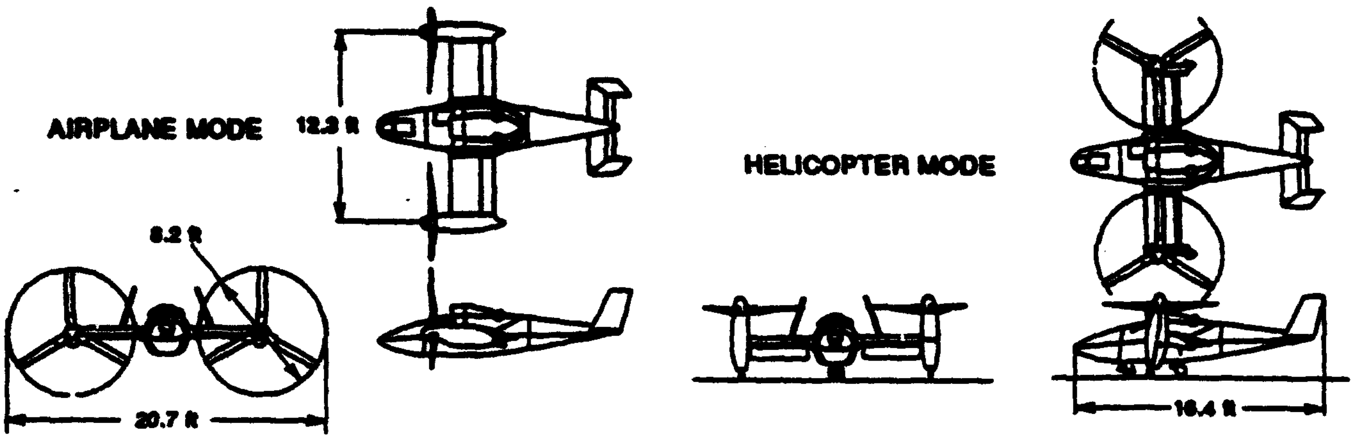

Figure 3
THREE VIEW DRAWING OF THE TRUS AIRCRAFT

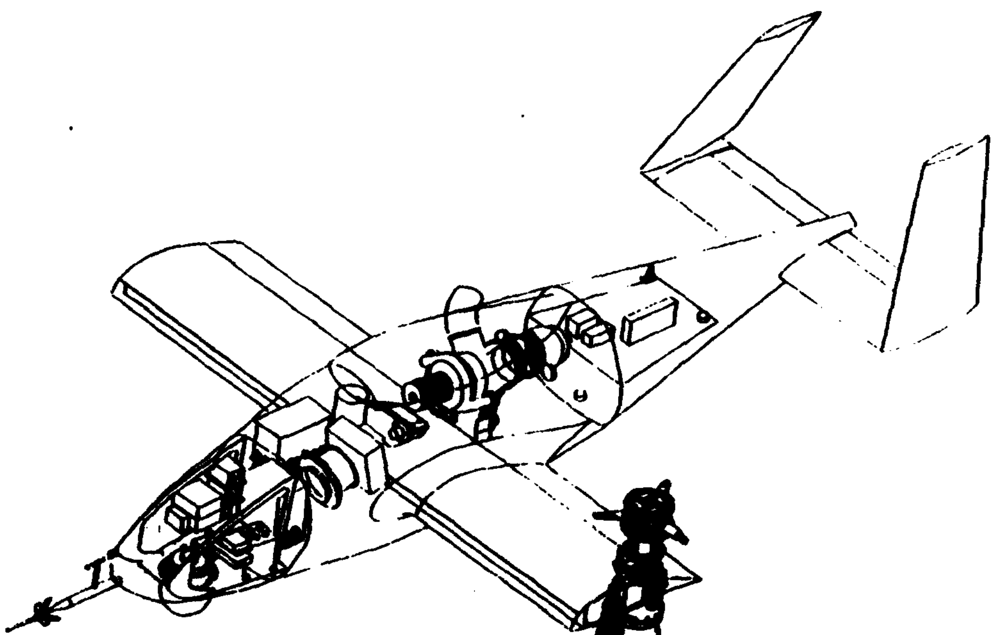

Figure 4
ISOMETRIC VIEW OF THE TRUS AIR VEHICLE

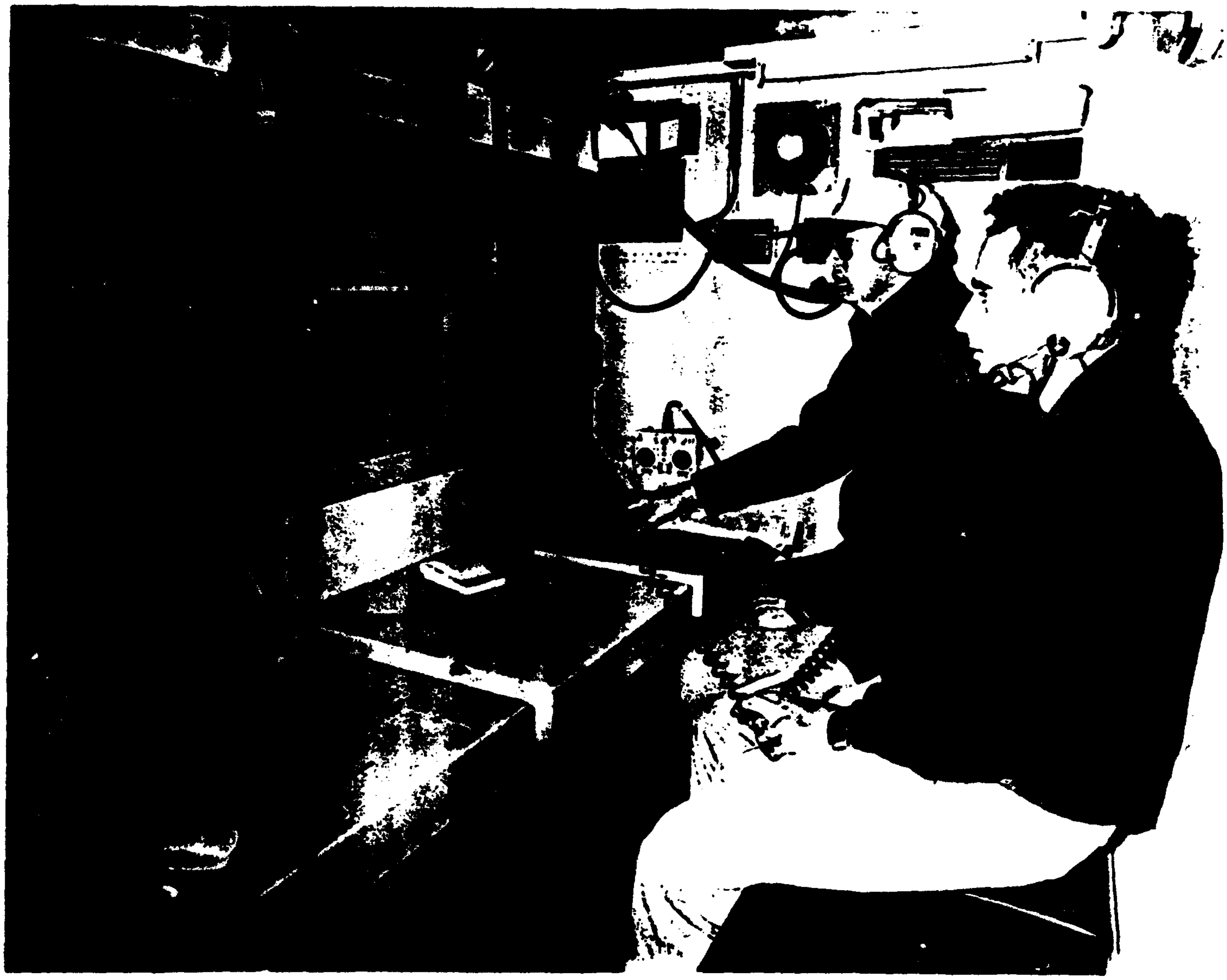

Figure 5
PHOTOGRAPH OF THE INSIDE OF THE GROUND CONTROL STATION (GCS)

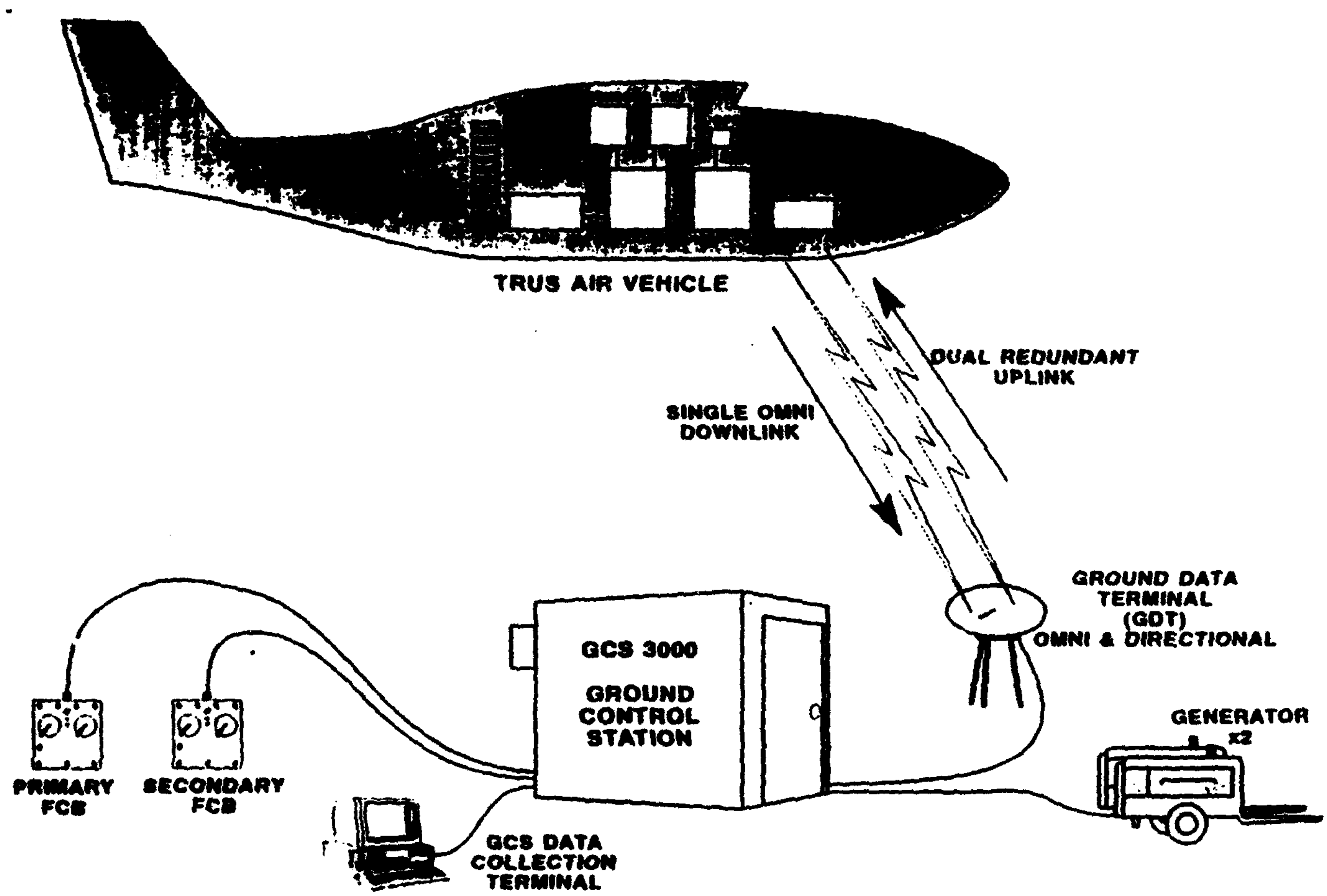

Figure 6
SCHEMATIC OF THE TRUS CONTROL SYSTEM

CONTROL	FUNCTION
VELOCITY SET:	IMU initialization
LAMP TEST:	lamp test
DIMMER:	lamp brightness control
NACELLE:	nacelle position fwd/aft control
LINK LOSS MODE:	switches between takeoff/land and return home modes for link loss
CONTROL:	transfers control to backup FCB
ENGINE:	engine master kill switch (w/lamp)
READY LAMP:	lit on FCB in control (primary or backup)
STUDENT LAMP:	lit on backup FCB
EXT PILOT LAMP:	lit on primary FCB
DIRECTIONAL:	yaw control and trim
VERTICAL:	vertical axis control and trim
LONGITUDE:	longitudinal control and trim
LATERAL:	lateral control and trim
AUTO HOVER:	inertial velocity mode on/off
LANDING GEAR:	landing gear retract/extend
MODE:	switches between ground (degraded) and normal (flight) modes (w/lamps)
ON/OFF:	spare switch

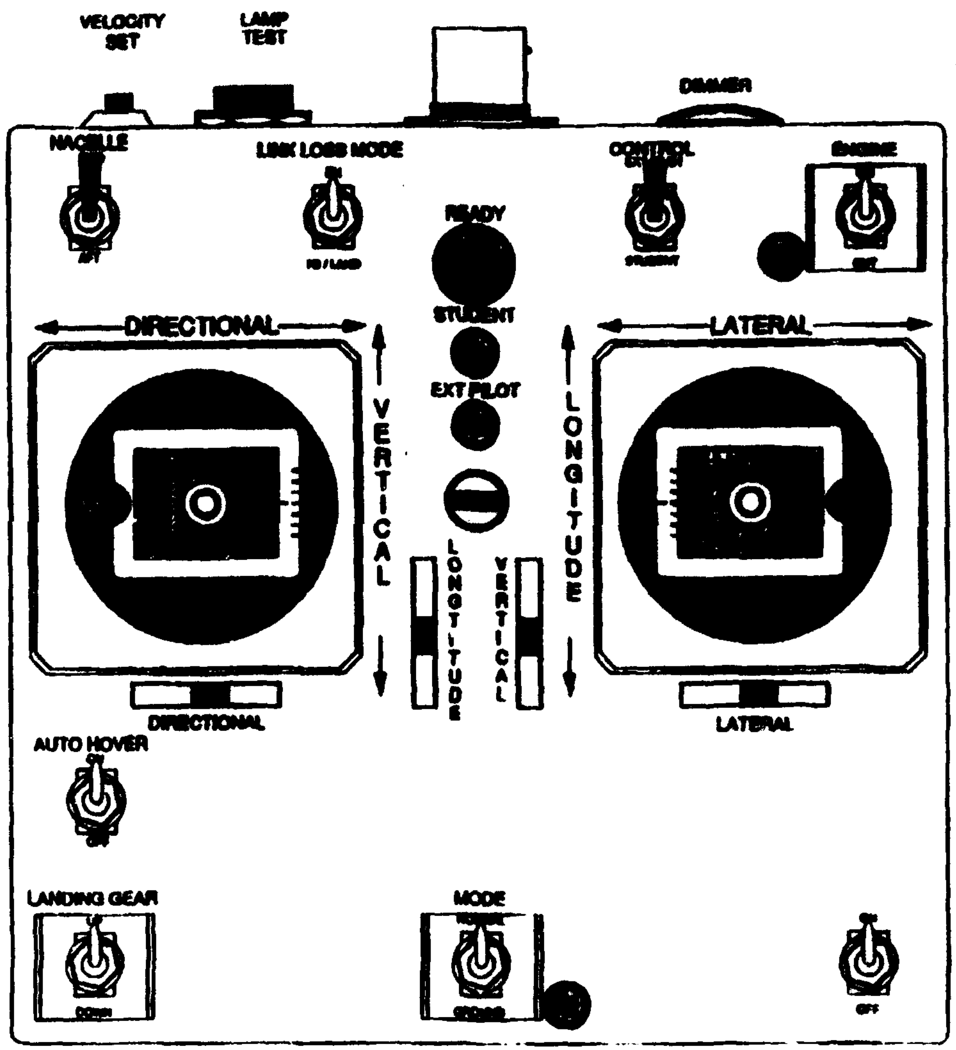

Figure 7
DIAGRAM OF THE FLIGHT CONTROL BOX (FCB)

CONTROL MODE	LONGITUDINAL STICK	LATERAL STICK	VERTICAL STICK	DIRECTIONAL STICK	NACELLE BEEP SWITCH
GROUND MODE	PITCH ATTITUDE COMMAND	ROLL ATTITUDE COMMAND	THRUST COMMAND	YAW RATE COMMAND	CONVERSION 80° - 93° LIMIT
AUTO HOVER MODE	LONGITUDINAL INERTIAL VELOCITY COMMAND. ±20 KN LIMIT INITIALLY.	LATERAL INERTIAL VELOCITY COMMAND. ±20 KN LIMIT INITIALLY.	VERTICAL INERTIAL VELOCITY COMMAND	YAW RATE COMMAND	CONVERSION 80° - 93° LIMIT (FUSELAGE DECK ANGLE TRIM)
HELICOPTER NORMAL MODE	(<40 KN) PITCH ATTITUDE COMMAND (>40 KN) AIRSPEED ACCEL.	ROLL ATTITUDE COMMAND WITH TURN COORDINATION ABOVE 40 KN	VERTICAL INERTIAL VELOCITY COMMAND	(<40 KN) YAW RATE COMMAND (>40 KN) DISABLED	CONVERSION 80° – 93° LIMIT
CONVERSION (>40 KN, <155 KN)	AIRSPEED BIAS ±20 KN FROM CENTER OF CORRIDOR	ROLL ATTITUDE COMMAND WITH TURN COORDINATION	VERTICAL INERTIAL VELOCITY COMMAND	STICK DISABLED ABOVE 40 KN. FUNCTION COMBINED INTO LATERAL STICK.	CONVERSION THROUGH FULL RANGE (0° – 80°)
AIRPLANE MODE (>115 KN)	AIRSPEED ACCEL / DECEL COMMAND	ROLL ATTITUDE COMMAND WITH TURN COORDINATION	VERTICAL INERTIAL VELOCITY COMMAND	STICK DISABLED FUNCTION COMBINED INTO LATERAL STICK	AFT ONLY

Figure 8

A MATRIX OF THE FLIGHT CONTROL BOX FUNCTIONS

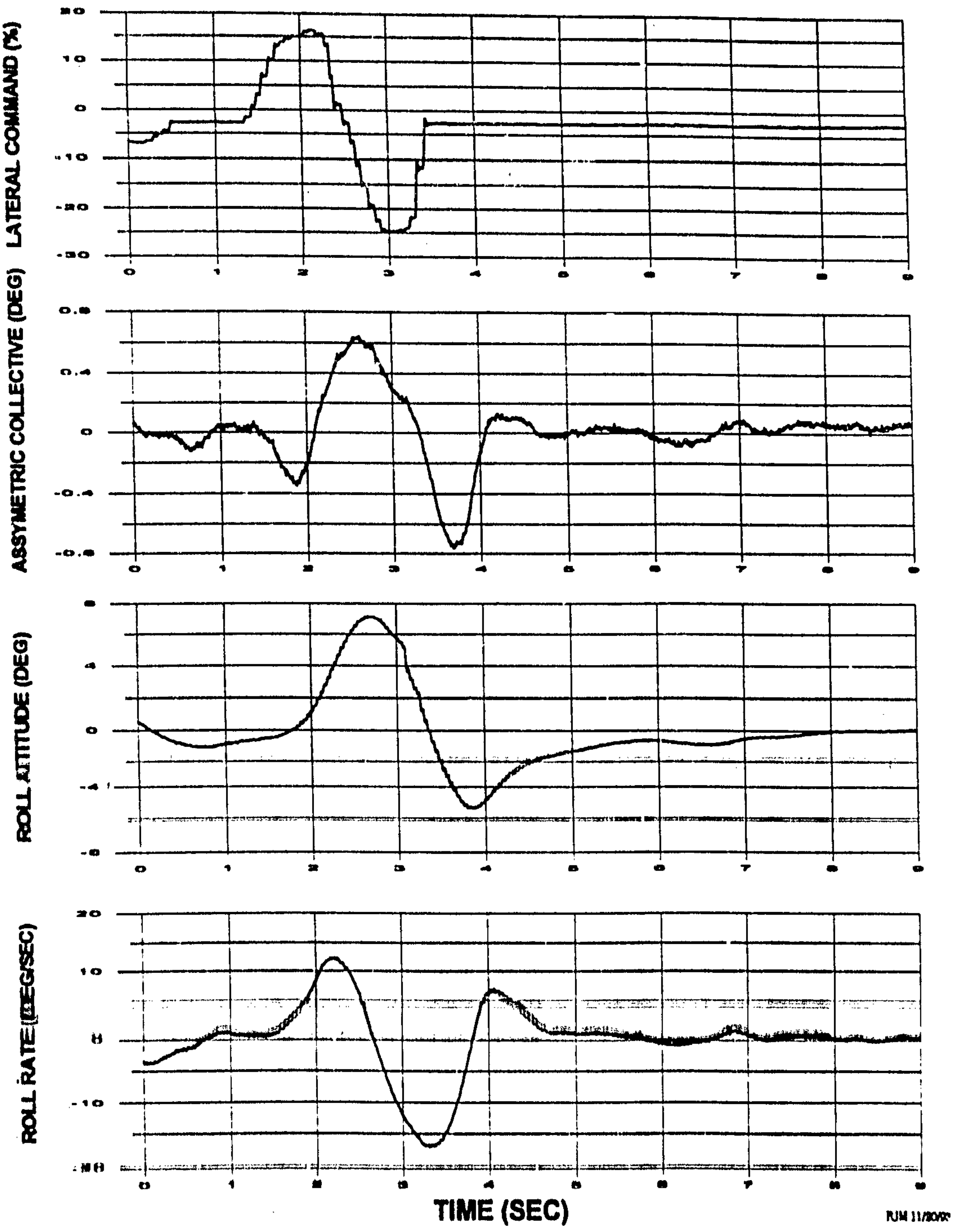

Figure 9
ROLL DOUBLET FROM A 15 FT AGL HOVER

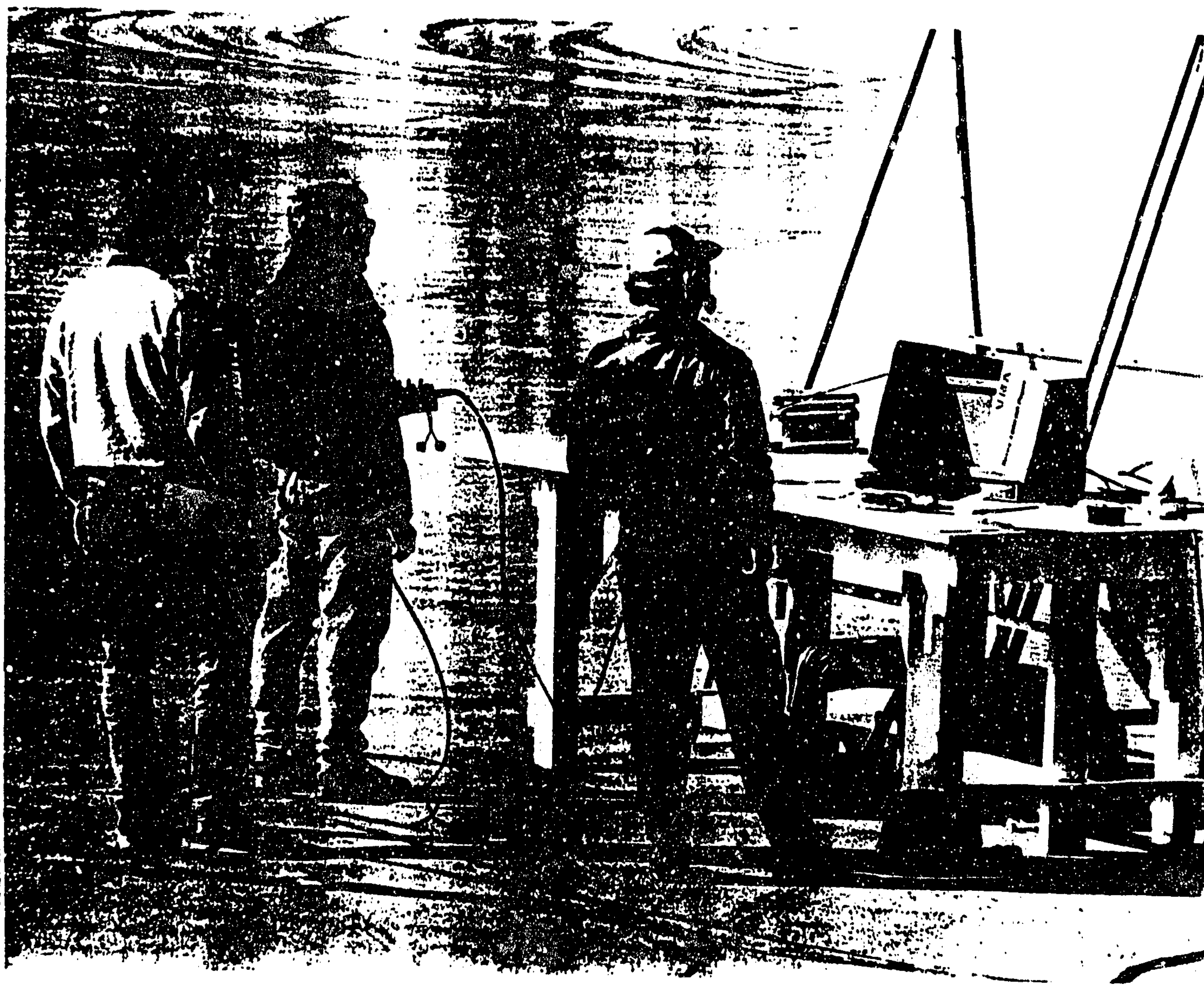

Figure 10
PHOTOGRAPH OF THE EXTERNAL PILOT FLYING THE TRUS

Flt #	Date	OAT (°C)	Barometer (in Hg)	Winds* (kt/dir)	Initial GW/CG (lb/in)	Final GW/CG (lb/in)	Flt Time (minutes)	Major Accomplishments	Reasons for Termination
1	Jul 10, 1993	23.3	30.0	6/S	1730.9/101.1	1676.5/101.0	14.9	First flight of aircraft # 1. Six takeoffs and landings.	Adjust flight control gains.
2	Jul 14	23.5	29.9	5/S-SW	1676.5/101.0	1644.6/101.0	8.7	Envelope Expansion.	Adjust flight control gains.
3	Jul 14	23.8	30.3	7-10/S	1746.6/101.0	1726.3/101.0	4.2	Continued envelope expansion.	ADU miscompare during landing.
4	Jul 16	25.6	29.97	5-10/S	1726.3/101.0	1707.9/101.0	4.5	Practice takeoffs and landings.	Engine chip light.
5	Jul 16	29.4	30.0	4-8/S	1733.3/100.9	1677.1/101.0	10	Practice takeoffs and landings.	Flight card completed. Training gear removed.
6	Jul 16	31.7	29.97	5-15/S	1643.1/101.0	crashed 90 lb of fuel used.	18	Met Government hover criteria requirements.	Flight card completed. Aircraft #1 crashed on final landing. Investigation initiated.
1	Nov 3	17.6	30.13	2-5/E-SE	1755.4/101.3	1670.5/101.3	24.5	First flight of aircraft #2. Lateral & longitudinal control response conducted.	Flight card completed.
2	Nov 4	26.6	29.71	5-7/W-SW	1762.3/101.3	1745.7/101.3	3	Flight control trim verification.	Precautionary landing conducted due to MGT +810 °C.
3	Nov 8	7.1	30.21	4-6/SE	1752.4/101.3	1714.6/101.2	7	First flight in normal mode.	Precautionary landing due to loss of C-band primary data link.
4A	Nov 9	10.5	30.31	3-4/E-NE	1769.0/101.3	see below	9	Flight control inputs in normal mode.	Precautionary landing due to loss of C-band primary data link.
4B	Nov 9	12.5	30.29	4-6/N	see above	1664.1/101.2	14	OGE hover in normal mode. First landing in normal mode.	Precautionary landing due to low fuel state. Flight card 80% done.
5	Nov 11	10.9	30.10	2-4/E-SE	1754.4/101.1	1691.3/101.1	10	Continued helicopter envelope expansion in normal mode.	Precautionary landing due to loss of C-band primary data link.
6	Nov 16	10.2	30.09	1-3/N-NW	1754.4/101.1	1730.0/101.1	7	Hover ladder from 20 to 3 ft AGL (wheel height).	Precautionary landing due to loss of GPS signal.
7A	Nov 17	10.9	30.10	2-4/S-SE	1756.1/101.1	see below	10	Hover ladder from 30 to 3 ft AGL (wheel height).	Precautionary landing due to loss of GPS signal.
7B	Nov 17	18.1	30.27	2/N	see above	1650.9/101.1	19	IGE translations at 10, 7, 3 ft AGL (wheel height).	Flight card completed.
8A	Nov 20	6.3	30.33	5-9/N-NW	1760.2/101.0	see below	17	First flight conducted without the training ger : on.(aircraft #2)	Aircraft climbed when auto hover engaged, flight terminated to investigate.
8B	Nov 20	10.6	30.32	2-7/N-NE	see above	1652.2/101.0	8	First successful flight in auto hover mode.	Precautionary landing due to loss of GPS signal. Flight card 90% completed.

Note: * Aircraft typically launched and recovered nose into wind.

Figure 11
TRUS DEMONSTRATION FLIGHT HISTORY

Flt #	Date	OAT (°C)	Barometer (in Hg)	Winds* (kt/dir)	Initial GW/CG (lb/in)	Final GW/CG (lb/in)	Flt Time (minutes)	Major Accomplishments	Reasons for Termination
9A	Jan 13 1994	14.4	29.56	0-4/N-NW	1754.0/101.1	1639.5/101.1	30	First flight Conducted at YPG. First "pattern work" conducted. First flight to use nose camera.	Trouble shoot auto hover problem.
9B	Jan 13	21.0	29.53	6-10/NW	1639.5/101.1	1593.5/101.2	10	Verified auto hover mode.	Flight card completed.
10	Jan 14	18.9	29.49	5-10/N-NW	1751.2/101.1	1703.2/101.1	12	Max forward airspeed: 36 kt. Max altitude: 350 ft AGL	Limited cyclic pitch authority.
11	Jan 19	18.3	29.45	3-8/N-NW	1748.5/101.1	1727.8/101.1	2	None.	Failure of the air data computer.
12A	Jan 22	12.2	29.39	1-3/Varbl	1747.3/101.1	1701.7/101.1	10	Verified ADU fixed.	Precautionary landing due to loss of GPS signal.
12B	Jan 22	17.2	29.50	1-3/N-W	1752.3/101.1	1566.3/101.2	62	First flight in airspeed mode. First inflight conversion from 90° to 85° nacelle angle. Evaluated turn coordination modifications.	Flight card completed.
13A	Jan 26	11.7	29.48	1-2/Varbl	1763.4/101.1	1610.3/101.1	52	Landing gear retracted inflight for first time. Nacelle conversion from 90° to 60° and back.	Precautionary landing due to loss of GPS signal.
13B	Jan 26	16.7	29.31	6-10/N-NW	1670.9/101.1	1592.8/101.2	25	Student pilot training conducted	Flight card completed.
14A	Jan 28	8.3	29.15	2-3/NE	1773.6/101.1	1705.9/101.1	23	First flight in conversion mode. Nacelle conversion from 93° to 50°.	Engine chip light.
14B	Jan 28	12.2	29.18	9-13/NW	1776.9/101.1	1692.2/101.1	27	Control inputs at 50° nacelle. Nacelle conversion from 93° to 32° and back. Max airspeed: 118 kt. Max altitude: 500 ft AGL	Precautionary landing due to inflight structural loads.
15	Feb 1	13.3	29.70	6-8/N	1777.1/101.1	1570.1/101.2	73	Nacelle conversion from 93° 15.7° and back. Student pilot training (25 min).	Low fuel indication. Flight card 95% completed.
16	Feb 4	11.1	29.34	2-3/S	1776.2/101.1	1726.2/101.1	14	Verified vertical control law change.	Precautionary landing due to loss of GPS signal.
17	Feb 9	10.0	29.42	1-3/N-NE	1779.5/101.1	1642.0/101.1	48	First full conversion to airplane mode, zero degree nacelle angle.	Flight card completed.
18	Feb 14	12.2	29.39	5-8/NE	1779.5/101.1	1582.1/101.2	75	N2 beeped back from 100% to 80%. Max airspeed: 160 kias. Max altitude: 820 ft AGL	Flight card completed.
19	Feb 15	15.0	29.43	1-3/S-SW	1775.6/101.1	1648.1/101.1	41	TRUS flight demonstration.	Flight card completed.

Note: * Aircraft typically launched and recovered nose into wind.

Figure 11 (Continued)
TRUS DEMONSTRATION FLIGHT HISTORY

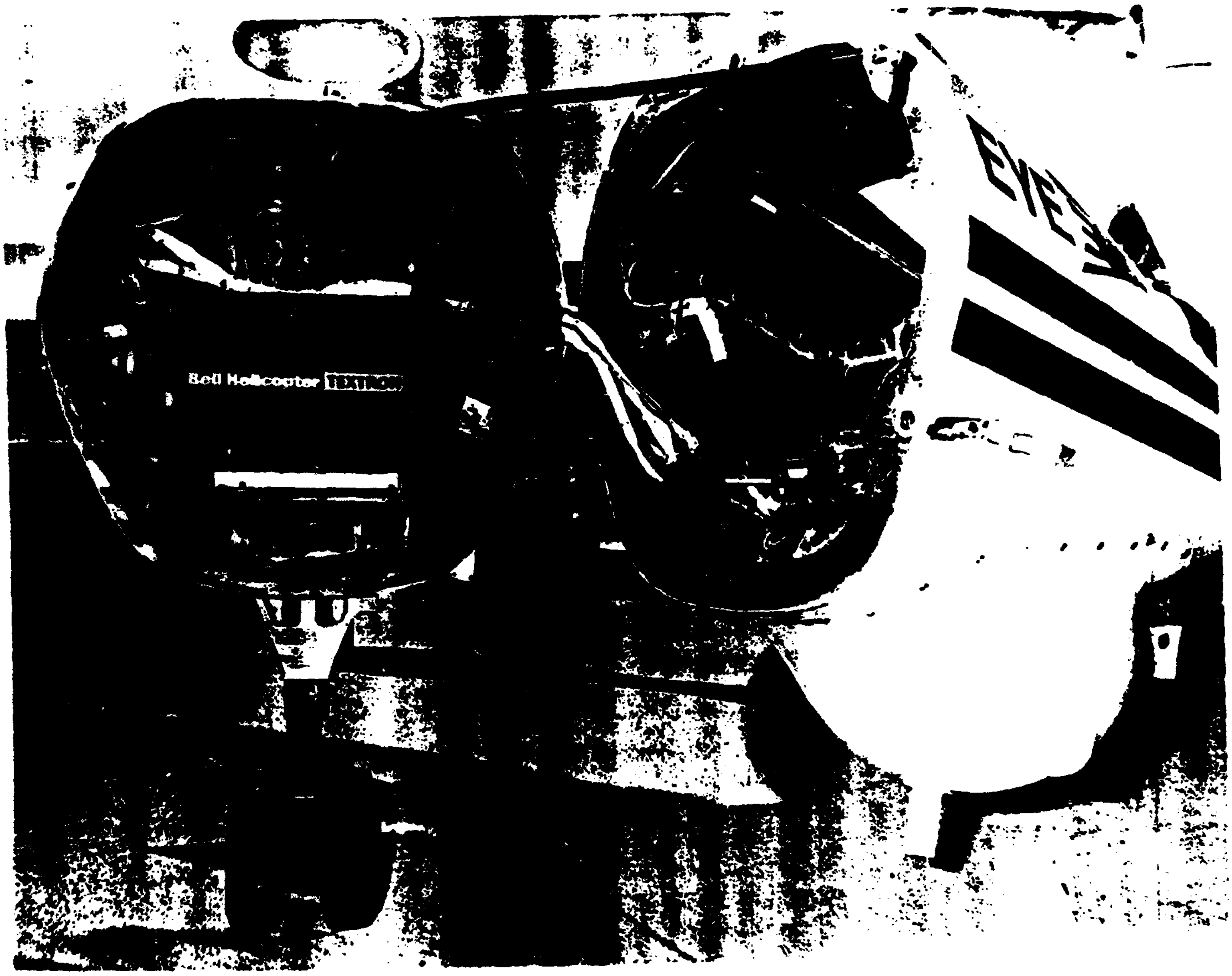

Figure 12
A PHOTOGRAPH OF THE TRUS MODULAR NOSE DESIGN

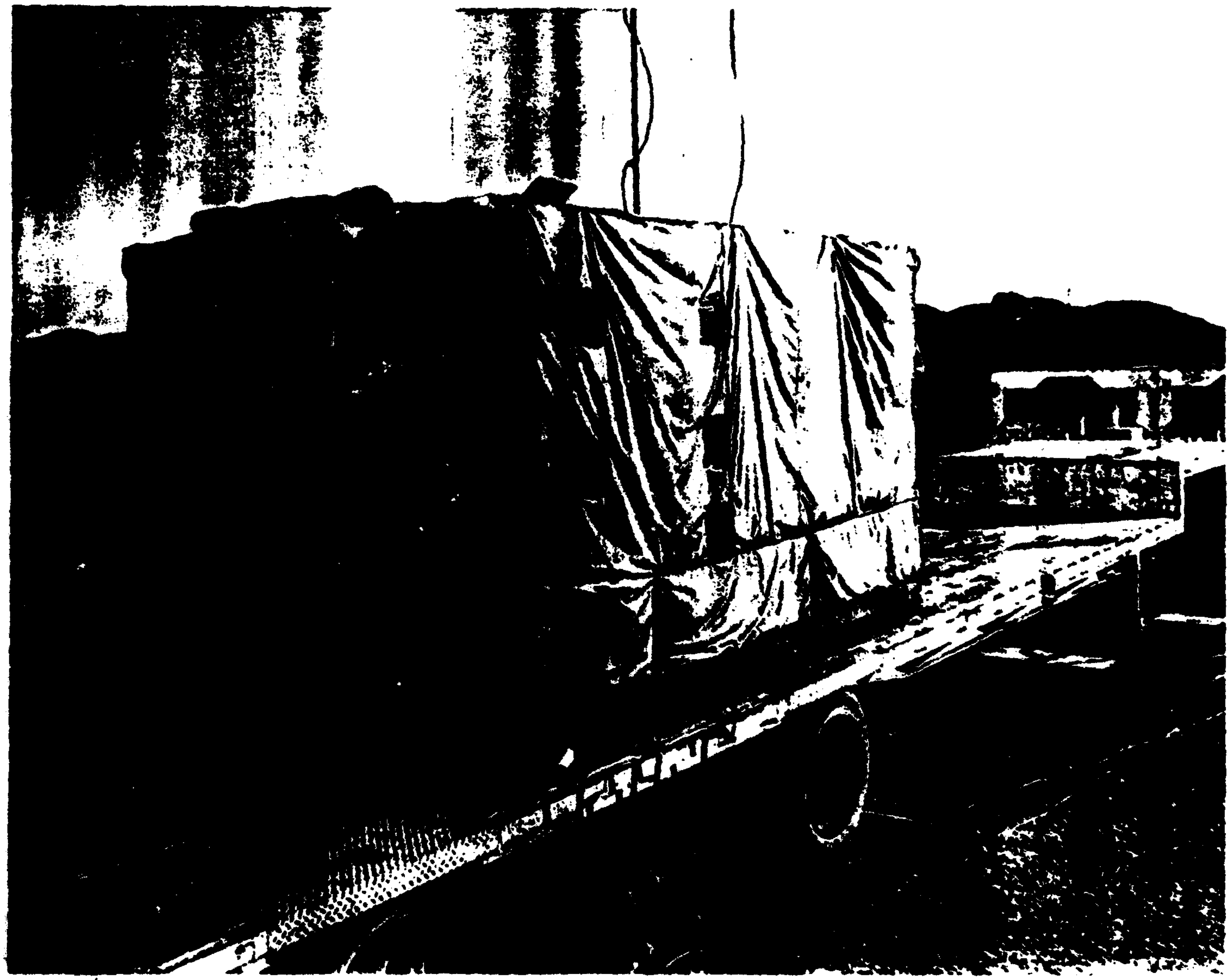

Figure 13
A PHOTOGRAPH OF THE OUTSIDE OF THE GCS